Developing Product Lifetimes Information System: First Results

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Abstract: While the planet is facing various environmental challenges associated with unsustainable levels of material consumption, governments and industries are more frequently considering policies and practices aimed at extending the lifetimes of manufactured products. Nevertheless, it is still quite challenging for eco-minded consumers to navigate across a variety of products looking for more long-lasting brands and models. To meet such consumer needs, the first online platform of its kind has been developed as part of this research (https://lt-platform.web.app/). It collects and stores consumers' reports on use and disposal patterns for various products they have owned. This allows analyzing the harvested data using Markov chains to estimate the durability (time until the first failure) and the total lifetimes (domestic service lifespan) of the different consumer products. Such results are updated live after every new contribution to the platform and are presented back in a user-friendly visual format ranking various products' manufactures and models according to the estimated lifetimes. Additionally, the structure of the collected data allows evaluating the effects of the different circular behavioural approaches (repair, re-use, recycling, etc.) on the products' longevity that could be of specific interest for researchers and policymakers. As a result, such a platform is the first attempt to collect and analyze products' lifetime and durability data in an open, centralized, and accessible format supporting users in their more sustainable consumer.

Introduction

Unsustainable levels of consumption are increasingly driving environmental challenges at a global level. Goods accounted for 14% of the total humanity's Ecological Footprint in 2020 while the total footprint far exceeds the planet's bio-capacity (WWF, 2020). These environmental impacts are associated with diverse stages of product life cycle such as manufacturing-related carbon emissions or waste-related water pollution (Hertwich, 2011).

One of the systematic approaches to mitigate such impacts is to extend the lifespan (lifetime or longevity) of consumer durables (Cooper, 2005; van Nes & Cramer, 2006). While several causes of product obsolescence have been observed, the technological type of obsolescence relates to the durability and reliability of the consumer goods (Hennies & Stamminger, 2016; van Nes & Cramer, 2006). Accordingly, extended product durability is considered to be one of the pillars of business' eco-efficiency (Stigson, Madden, Young, Brady, & Hall, 2006). However, most corporations do not target extending product durability as they are not compensated for the corresponding lack of production and sales (Nazzal, Batarseh, Patzner, & Martin, 2013) apart from businesses that pursue servitization models (Vendrell-Herrero, Vaillant, Bustinza, & Lafuente, 2021). Meanwhile, durability-related considerations do affect consumers' purchase choices (Floyd, Freling, Alhoqail, Cho, & Freling, 2014). Still, while it appears reasonable to empower consumers with accessible and reliable information on the durability of various goods, brands, and models, such information services are hardly available. The average inter-purchase time data analysis has been proposed as a measure of product and brand durability (Ching, Erdem, & Keane, 2020). However, it can be argued that there are other causes to purchase a product replacement apart from the technical failure and physical wear and tear (functional obsolescence) such as the aesthetical depreciation of a functional product (psychological obsolescence).

Moreover, geographically and time referenced data on product lifespan is important in the fields of material flow and stock analysis, life cycle assessment, as well as in marketing applications (Murakami, Oguchi, Tasaki, Daigo, & Hashimoto, 2010). Four types of methods that differently use market statistics data, discard surveys, or yearly use surveys to estimate the lifespan distributions of commodities are currently distinguished in the scientific literature (Oguchi, Murakami, Tasaki, Daigo, & Hashimoto, 2010). Only the discard surveys (either through consumer questionnaires or at the treatment facility) do not require extensive shipment statistics or multi-year surveying to estimate the total domestic lifespan. Yet, the consumer discard surveys usually estimate the possession span of an average owner instead of the total domestic service lifespan that includes all the owners of a product given the second-hand markets (Oguchi et al., 2010; Steffens, 2001). Meanwhile, surveys at the waste treatment facilities appear to be quite time and cost-intensive (U.S. EPA, 2008). Finally, the attempts to deliver actual and comprehensive databases are extremely limited. At the time of this work, the only similar attempts identified were the LiVES database that has been last updated 11 years ago (Murakami et al., 2010) and the International Service Life Database for buildings which has been discontinued (Daniotti, Lupica Spagnolo, S. Chevalier, Hans, & Chorier, 2010).

To respond to such consumer, industrial, and academic data demand, we have developed an open-collaborative online information system that collects consumers' reports on the life-cycle data of the goods they have owned and used. The collaborators are supposed to be attracted to the platform as it analyses the previously harvested data and provides real-time rankings on the most durable product brands and models on the market with their average lifetimes. At the same time, the database collects data for various years, regions and use phases of the reported commodities. The newly proposed method for lifetimes estimation, based on Markov chains, allows estimating various lifespan types including the important total domestic service lifespan without reliance on auxiliary market statistics and laboratory or waste facility-based analysis. Finally, the underlying data structure allows evaluating the impacts of various circular behavioural approaches such as repair and re-use on product longevity.

This study will follow by introducing the scope of the definitions, the description of the proposed approach to measure the durability and the total lifespan of products, and the current results of such analysis.

Methods

Definitions

Commodity durability has been measured in various ways. First of all, durability can be assessed either based on time or usage perspectives, for instance, years in service versus total mileage for vehicles (Suzuki, Alam, Yoshikawa, & Yamamoto, 2008). Furthermore, it can be measured via laboratory analysis ("Which?," 2021) or statistically from observations, with the latter approach considered to be more realistic as it allows to account for the environmental conditions of usage (Suzuki et al., 2008).

In this paper, the durability of a product is defined as its capacity to last and is measured as the expected time from the initial purchase until its first failure (TUFF): the total durable span. The failure can be either minor (limited usability) or major (not usable anymore) and any of them counts towards TUFF. We show that such measure, given survey data for the newly purchased and later failed product, allows to accurately represent the relative reliability of brands and models.

As for the total product lifespan (lifetime), we use the existing definition of the domestic

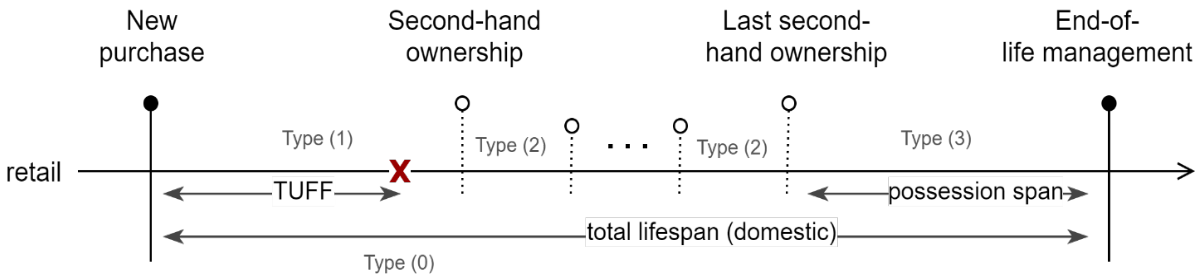

Figure 1. Domestic life cycle model along with the four types of ownership, durable span (TUFF), possession span, and the total lifespan

service lifespan: the time between the purchase by the very first owner and the time when the product is ready for the end-of-life (EoL) management (Oguchi et al., 2010; U.S. EPA, 2008). In this paper, we assume the shipment span (time between production completion and the first purchase) as zero. Such total product lifespan, hence, will include the procession spans by each owner along the product's life cycle. By definition, the expected durable span is not longer than the expected total lifespan of a product. The ratio between the expected durable span and the expected domestic span shows the relative tendency of a product type to be used or hibernate after it failed and before its EoL.

The goal of this work was to develop an online platform that will collect consumer reports and publish in real-time the resulting average total lifetimes and the TUFF of products.

Model

Here, we introduce the proposed computational model and the corresponding data structure. We distinguish four possible ownership prototypes until the product is discarded through EoL management by the last owner. Type (0) is the single ownership pattern where the first user becomes the product's last user and discards it either through designated recycling or regular waste treatment services. Type (1) is the ownership phase of the first user who purchases a new commodity and later disposes it of either through giving it away or selling it to the second owner. Type (2) implies the possession span between the previous and the proceeding user of the used product. Type (3) is the span scoped by the very last user who receives a used product and discards it in the end. The following Figure 1 illustrates this model including the definitions introduced above.

Additionally, we consider that products can be returned to the retailer that additionally increases their total lifetime depending if they are later refurbished for re-selling or directed to the EoL management.

Moreover, we distinguish five conditions the products can be possibly in: new, new - refurbished, used (functional), used - minor malfunction (limited experience), and used - major malfunction (not usable).

Such model of the product life cycle between its initial shipment and the EoL management can be presented in the form of a Markov chain that is defined as a discrete set of states (Z), the initial state N, and a sequence of random variable X in Z such that the transition probability p_{ki} of occurrence of the next state i is defined only by the current state k and is given in matrix P (Feldman & Valdez-Flores, 2010). In our case, we consider the following space of states: R (retail), N (new product reaches first owner – the initial state), S (second-hand product received by new owner),

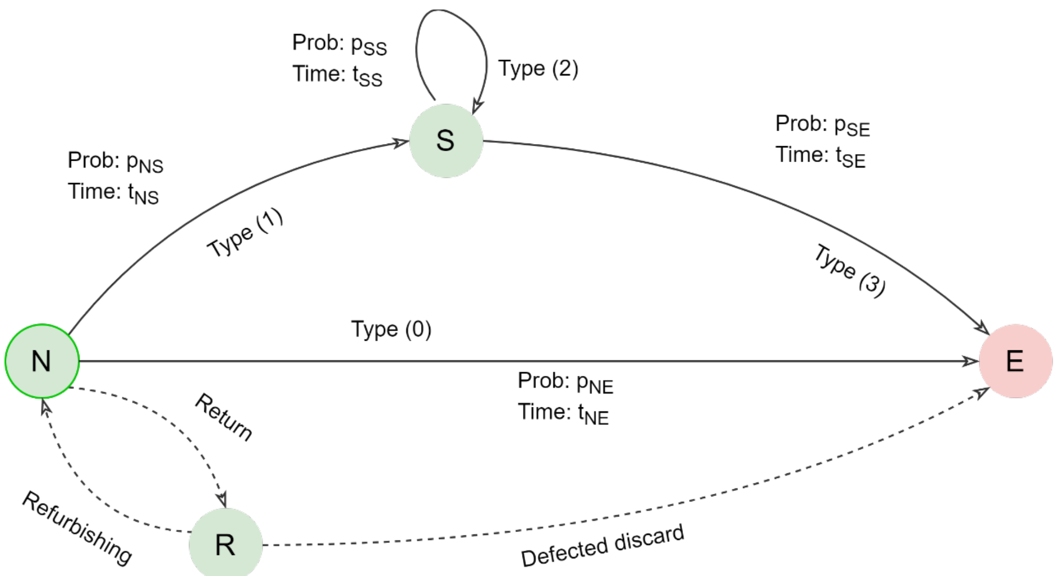

Figure 2. Markov chain describing the proposed stochastic model of product domestic life cycle. N is the initial state, E is the final state.

and E (the EoL state at the moment of discard). Additionally, we assign a set (T) of weights t_{ki} to the edges to represent for how long on average does the product stay in the state k before transiting to i. This is represented in the Figure 2.

Using the theoretical framework of Markov processes, the total product lifespan can be, then, calculated as an expected *hitting time* h_N to reach the final (absorbing) state E from the initial state N. The following system of linear equations has to be considered where p_{ik} is a transition probability from state i to state k and t_{ik} is the average time span between states i and k:

$$h_i = \sum_{k \in Z} p_{ik}(h_k + t_{ik})$$

Solving the system will deliver the expected total lifespan (h_E).

The durable span is obtained in an analogous way where the absorbing state is replaced with the TUFF state, and P and T are adjusted accordingly.

Data structure

The comprehensiveness of the proposed model allows to avoid restricting the survey participants as reports related to any phase of the product lifecycle (ownership types 1 to 4) are in the end contributing to the more accurate P and T estimation. In particular, we calculate the values for the probabilities $\mathrm{p_{NS}} + \mathrm{p_{NE}} + \mathrm{p_{NR}} = 1$ and $\mathrm{p_{SE}} + \mathrm{p_{SS}} = 1$ based on the relative difference between the number of respondents reporting such transitions during their consumer experience. The probabilities $\mathrm{p_{RN}} + \mathrm{p_{RE}} = 1$ do not relate to the consumer experience, however, and have to be sourced from the retail statistics on which share of the returned product are refurbished for reselling.

Data on the average time that each lifecycle stage lasts is calculated as a mean value for all the possession spans reported within such ownership type (1 to 4).

Additionally, temporal data on the hoarding time (hibernating products) and repair behaviour are collected to accurately estimate the durable span.

Additionally, the following non-temporal data is collected: product brands and models, geographical data, method of product disposal, and consumer's subjective evaluation of how expensive the product is to support the corresponding analysis.

Web-platform and the database

The Product Lifetimes & Durability Portal has been developed to achieve both, the data harvesting and data sharing purposes of the presented work: www.lt-platform.web.app (currently in the trial mode). The portal is two-sided in the sense that it provides one page that collects reports from respondents that adheres to the previously described model for the selected product type, and the other page that presents the consumers and practitioners with the relevant rankings and analysis. The reports are envisioned to be collected either from benevolent contributors who are interested in the information provided in return or from the target surveys. In the latter case, the respondents have to add a unique survey ID to their report so that data collected in that way can be distinguished from the rest of the database. All the analyses are automatically performed on the fly on the back-end and are immediately presented back to the user.

Results and discussion

Experiment for consumer electronics

To verify the validity of the proposed model and to exemplify the usability of the designed portal and resulting data, a survey-based experiment has been conducted. In particular, 123 respondents through paid MTurk service have been recruited to submit data (through the portal) regarding their experience with 11 categories of major consumer electronics as ICT and consumer electronics contribute up to the 80% of the total e-waste (Forti, Baldé, & Kuehr, 2018). Only products that are not used or owned anymore were asked to be reported. Product return and refurbishment transactions were not considered in this study. For all the electronics reported the procession span has been estimated based on the Type 0 spans (new products discarded), and then the total lifespan has been estimated considering all ownership phases based on the presented stochastic process model. Simplified assumptions were made for some products and phases where data availability was limited. Additionally, outliers were removed from the reports. Commodities with the most abundant data (at least 15 reports) were then compared against existing data on electronics lifetimes from United Nations University (Forti et al., 2018).

Results

As a result, 257 product reports have been submitted. The respondents were mostly from the USA (59%) and India (21%). 38% of the reported products are not in use however are still in procession suggesting a high volume of hibernating stocks. The overall distribution of the ownership phases reported for the disposed of products is presented under the following Figure 3:

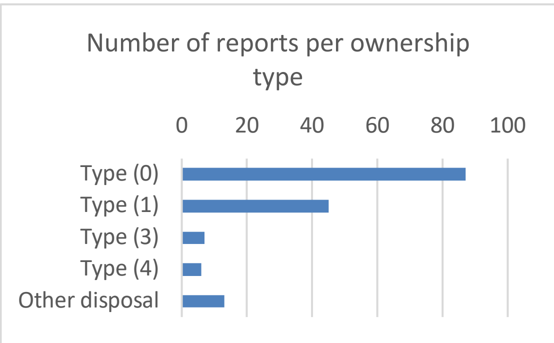

Figure 3 Distribution of submitted MTurk reports between different ownership types

The majority of participants discard their new purchases (Type 0), however, a significant number of products enter the second-hand market (Type 1).

The resulting Table 1 lists products with at least 10 reports submitted along with the estimations for the durable span, possession span, and total lifespan. Additionally, the total lifespan is compared against existing theoretical data.

When compared with the existing theoretical values for the total domestic lifespan, the average relative deviation error of our approach is only 14%.

The hibernation ratio between the durable span (measured based on Type 1 reports only) and the possession span (measured based on Type 1 reports only) shows how long the product is stored on average after the failure. The results show that, out of the listed electronics, TVs tend to be disposed of quicker after failure compared to digital cameras that are stored relatively longer.

The web portal additionally lists the top lasting brands to attract new visitors to the website, see the example below (Figure 4).

The SquareTrade report (Sands & Tseng, 2009) ranks these five brands in the following order: Asus, Sony, Dell, Acer, HP. This well matches the presented results suggesting that the platform has the potential to extract valuable durability information for consumers when larger-scale surveys are conducted and more reports are collected.

To conclude, the proposed stochastic model allows estimating the total lifespan of electronics with a high degree of accuracy without conducting facility-based discard surveys or using market data. A web portal with the capability of both collecting and analyzing lifespan data has been developed and presented.

Product	Reports	Possession span (Type 0)	Durable span	Hibernation ratio	Total lifespan	Total lifespan (UNU)
Desktop PC	27	4.50	4.20	0.93	12.1	9.2
Laptop computer	77	6.90	5.80	0.84	8	7.8
Printers (incl. scanners, etc)	24	5.70	5.10	0.89	7	7.6
Mobile phones (smartphones)	69	2.80	2.60	0.93	3.4	5.1
Digital cameras	18	6.30	5.10	0.81	6.3	6.36
TV (Flat Panel Display)	15	8.00	7.60	0.95	9.2	9.7

Table 1. Results for the products with at least 15 consumer reports collected. UNU – United Nations University report's resulting average years for the corresponding products (Forti et al., 2018)

#	Brand	Lifetime (years)	Time until first failure
1	ASUS	11.0	11.0
2	SONY	11.0	8.0
3	DELL	9.3	6.3
4	ACER	8.4	7.9
5	HP PAVILLION	7.4	6.8

Figure 4. Example of the lifetime ranking presented at the web portal for laptop computers. Based on the Type 0 reports only. Source: https://lt-platform.web.app/

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